CREATING NUTRIENT SUSTAINABILITY INDICATORS FOR DAIRIES NATIONWIDE

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SUSTAINABILITY IN THE AGRICULTURAL SECTOR

Sustainability of agricultural production is a discussion issue that occurs on agendas more and more often. On a global scale, this is born out of necessity, as the world population has been increasing gradually and is projected to expand further over the coming decades. By 2050, the planet will be home to more than 9 billion people, which all need to be fed. It is clear that this demands a major increase in agricultural production.

The resources required for the intensification of agriculture, such as land, water, and nutrients, are often scarce and/or non-renewable. Simultaneously, inadequate use of these resources may not only lead to waste, but also to degradation of the environment. Soil erosion, salinization, and eutrophication of water bodies like rivers, streams and lakes are ubiquitous problems that can decrease the suitability of agricultural land for future cropping and negatively affect terrestrial and aquatic ecosystems across various spatial and temporal scales. In the Northeastern US, the recurrence of water quality and air quality challenges has farmers, farm advisors, industry partners and policy makers wondering about long-term solutions. Proper resource use is key to achieve a sustainable increase in productivity necessary to feed a growing population.

It is hardly surprising that many ag-related organizations, companies, and governmental agencies have adopted a focus on sustainable production in recent years. The manner in which this occurs varies widely by organization. The Food and Agriculture Organization (FAO, 2014), for example, has identified five principles that should guide the process of transitioning towards a more sustainable agricultural sector:

"The principles which can collectively guide the process of transition to greater sustainability are summarized as:

- *Improving efficiency in the use of resources is crucial to sustainable agriculture*
- *Sustainability requires direct action to conserve, protect and enhance natural resources*
- *Agriculture that fails to protect and improve rural livelihoods and social well-being is unsustainable*
- *Enhanced resilience of people, communities and ecosystems is key to sustainable agriculture*
- *Sustainable food and agriculture requires responsible and effective governance mechanisms"*

The USDA Sustainable Agriculture Program wields a legal definition for the term ‘sustainable agriculture’ (USDA, 2007):

“The term ''sustainable agriculture'' (U.S. Code Title 7, Section 3103) means an integrated system of plant and animal production practices having a site-specific application that will over the long-term:

- *Satisfy human food and fiber needs.*
- *Enhance environmental quality and the natural resource base upon which the agriculture economy depends.*
- *Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.*
- *Sustain the economic viability of farm operations.*
- *Enhance the quality of life for farmers and society as a whole.”*

Many organizations in the dairy industry, such as FrieslandCampina, Dairy Farmers of America, Ben & Jerry’s, and others have sustainability programs, either individually or in collaborative efforts such as the Sustainable Agriculture Initiative (SAI) platform that includes suppliers, farmers, and external stakeholders. These programs have often adopted their own definition of sustainability.

Although many organizations have sustainability definitions and mission statements, few developed key performance indicators for sustainability. Those who have developed metrics or are in the process of doing so, tend to focus on environmental and socio-economic indicators. One example is the Fields to Market organization that created national indicators for environmental sustainability (Field to Market, 2016), which include environmental indicators (biodiversity, energy use, greenhouse gas emissions, irrigation water use, land use, soil carbon, soil conservation, and water quality), economic indicators (farm financial health, farm profitability, and generation of economic value), and social indicators (work safety and labor productivity).

Much of the focus of various sustainability platforms relates to external outcomes. While important, these overlook the fact that dairy farmers are by and large, nutrient managers. By looking within the dairy farm system, and attempting to utilize nutrients as efficiently as possible, significant source reduction can be obtained, providing important complementarity to minimizing external impacts, such as nutrient loss to water bodies.

There are 17 essential nutrients of which nitrogen (N), phosphorus (P) and potassium (K) are the three primary macronutrients for plant growth and animal performance, taken up in large amounts. Especially N and P are recognized as potential contributors to environmental degradation of air and/or water. Thus, if we are to move forward with assessment and documentation of sustainable food production in the dairy sector, it is crucial to have key indicators of performance and sustainability for N and P use, in addition to other indicators (e.g. for water use and greenhouse gas emissions).

Current programs, including Field to Market, do not address sustainability indicators for the dairy sector at this point. In addition, the nutrient indicators that are used, often do not address performance on a whole-farm scale. Sustainability indicators can provide a means to see instantly whether a system, such as a farm, has opportunities to improve its resource allocation to become more sustainable over time. The nutrient use of a farm is particularly suited for the use in sustainability indicators and such dairy sustainability indicators are needed to aid in implementation of improved management practices, to develop such practices, and to monitor the progress made in the industry.

There are several advantages and uses to the implementation of a broadly supported nutrient sustainability indicator. It can inform consumers about the origin of the product they buy and it can be used by dairy companies as an incentive to reward producers for sustainable practices. Simultaneously, it can give farmers insight in their nutrient use and how to improve it. It allows them to see whether they can produce the same amount of milk, using fewer nutrients and it may help reduce losses of valuable nutrients to the environment.

A DAIRY NUTRIENT SUSTAINABILITY INDICATOR

Compared to resources like land, soil, or energy, the use and transport of nutrients on dairy farms can be quantified with relative ease. For many parts of a dairy farm, there are indicators or tests that assess the efficiency of nutrient use. Examples include Milk Urea Nitrate (MUN) in milk, the corn stalk nitrate test (CSNT), soil test analyses, and the availability of manure nutrients. A whole farm indicator recognized that animal, the land, manure, feed storage, and barn management are all interconnected but such indicators are far less common.

The success of a dairy nutrient sustainability indicator relies on its characteristics. In short, a successful sustainability indicator:

- is easy to interpret;
- gives a measure of how sustainably the system is managed;
- sets targets for farmers to strive for;
- is responsive to significant management changes;
- takes a limited time to calculate/conduct.

One of the additional advantages of assessing nutrient management on a whole farm scale is that the boundaries (of the farm) are clearly marked. Furthermore, the errors at the farm level are typically smaller and less variable than for indicators that operate on a smaller scale.

THE WHOLE-FARM NUTRIENT MASS BALANCE

The whole-farm nutrient mass balance (NMB) is a nutrient assessment tool for nitrogen (N), phosphorus (P) and potassium (K) that meets the requirements for a successful sustainability indicator as described in section 2. A whole-farm NMB is calculated by subtracting the annual sum of nutrients exported from a farm from the nutrients imported onto the farm (Figure 1). The difference between these imports and exports is called the balance, and this is a measure of how many nutrients remain on the farm or are lost to the environment. The balance is expressed per tillable farm acre or per cwt of milk sold. The balance per tillable acre gives an indication on how many nutrients remain per acre, and is thus a measure of the environmental impact of a farm. The nutrient balance per cwt of milk sold is a measure for the amount of nutrients “used” to produce a unit of milk. This tells us something about the efficiency at which the farm operates.

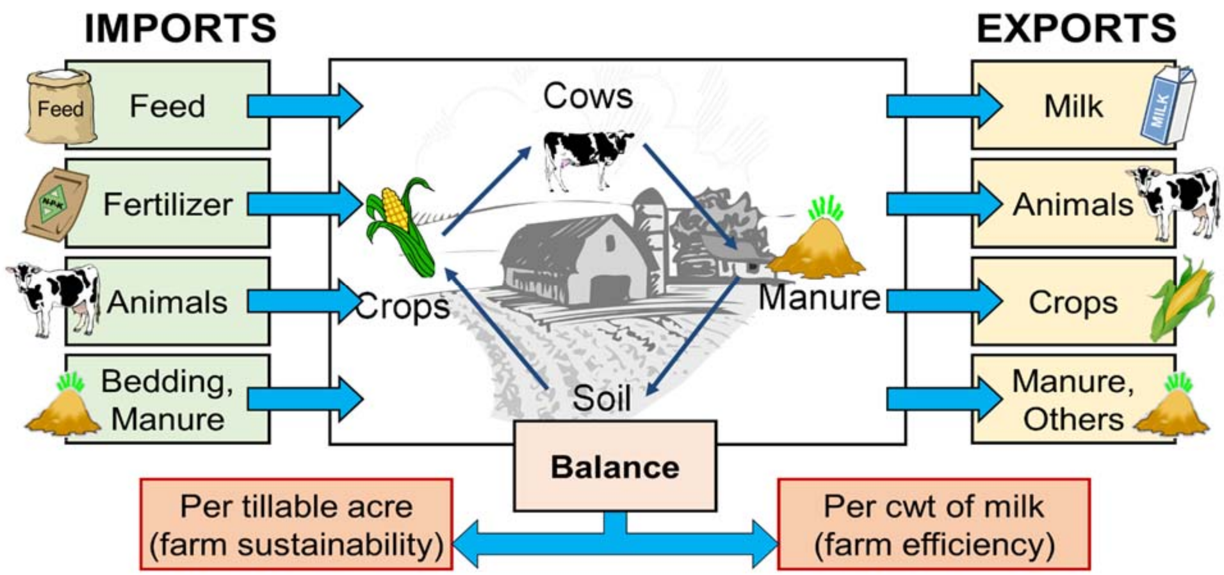

Figure 1. Overview of farm imports and exports included in the NMB. Only easily measurable components are considered. The nutrients in the resulting balance either remain on the farm system, or are lost to the environment.

The whole-farm NMB estimates a solid indicator from a relatively small amount of data. To conduct a NMB assessment, farmers are asked to fill out four sheets of paper with information on the size of the farm (number of acres and number of cows) and on any nutrient-containing imports and exports that entered or left the farm during a calendar year. These numbers are entered in the Cornell Nutrient Mass Balance software, which calculates the N, P, and K balances for the farm (Soberon et al., 2013).

For imports, the NMB distinguishes between feed imports, fertilizer imports, purchased animals, and bedding/manure. For exports, nutrients sold in milk, animals, crops, and manure or other products are considered. Information on the quantity and the nutrient content of all these commodities is needed to calculate the total amount of N, P, and K that enters and exits the farm. Furthermore, information is gathered on the forage and grain feed grown on the farm. Although this does not contribute to the balance itself (as homegrown feed is neither an import nor an export) it allows for the calculations of key performance indicators that can tell us more about the efficiency of the farm and opportunities to improve over time where feasible.

We can roughly distinguish three types of nutrient balances: negative balances, slightly positive balances, and largely positive balances. Negative balances have higher exports than imports, which means that there is a net flux of nutrients off the farm. On the short term this can be desirable, especially if nutrient levels in the soil are high. However, if negative balances are sustained over a long time, soil mining of nutrients (such as P and K) may occur and homegrown crops may not yield optimally. Slightly positive balances are desirable, as biological processes always need inputs that are a little larger than the outputs. It is therefore expected that nutrient imports are often larger than the exports, and as long as the difference remains small enough, this is a sustainable practice. However, when the nutrient imports are a lot larger than the exports, there is an increased risk of environmental losses. Although the difference can temporarily be stored in feed stocks on the farm, the remainder is often lost (this is mainly the case for N) or stored in the soil and slowly lost over time (for P and to a lesser extent for K). Sustained large balances can result in loss of N, P, and K to surface waters.

Table 1. Feasible balances for dairy farms in New York.

Nutrient	Lbs per acre	Lbs per cwt milk
N	0 ≤ 105	0 ≤ 0.88
P	0 ≤ 12	0 ≤ 0.11
K	0 ≤ 37	0 ≤ 0.30

The ideal level of an NMB is thus larger than zero, but not so large that the nutrients are used inefficiently, as this costs money and is potentially harmful to the environment. As a good indicator sets targets, it is essential here to have a range of balances per nutrient to aim for. To find this range, 102 balances from New York dairies were investigated. Feasible balances per acre were set at the third quartile of the farm distribution. In other words: if 3 out of 4 dairy farms in New York can achieve to be below a certain balance, this should be feasible for the other farm as well. For the balance per hundredweight (cwt), farms were divided in two groups, those below and those above the average balance per cwt for all farms (Cela et al., 2014).

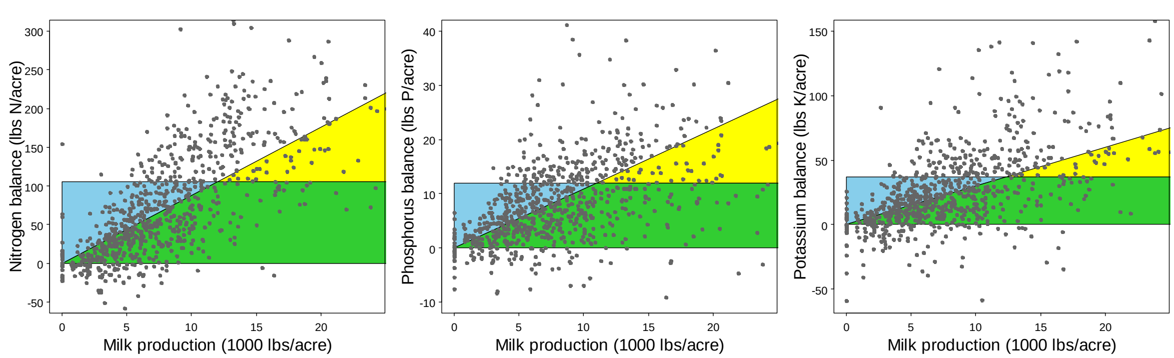

Figure 2. Optimal operation zones for N, P, and K. The grey dots represent farm records collected over the past decade. Farms in the green box have feasible balances per acre and per cwt.

The limits for balances per acre and per cwt (Table 1) can be combined per nutrient into one figure, to describe an optimal operation zone, or Green Box (Figure 2). This allows for a quick indication of a farm's sustainability. Farms that are in the green box have both feasible balances per acre and per cwt. Long-term records from a number of farms indicated that balances can be maintained in the "Green Box" for many years in a row (Soberon et al., 2015; Cela et al., 2015).

Because there is information on the crops and nutrient amounts grown on-farm as well, the NMB assessment can provide efficiency indicators beyond the balances. These indicators can give insight in why a farm operates within or outside the green box. For most of these indicators, a threshold value is derived. Should a farm cross this value, it is likely that it will operate beyond the feasible balances. This way we can indicate where the farm is likely to have the largest opportunities of improving the balances. In the example below (Table 2), the Example Farm has high N fertilizer imports (64 lbs/acre) which may have contributed to the high N balances (106 lbs/acre and 1.09 lbs/cwt). The N imported through feed (107 lbs/acre), however, is not crossing the indicator. This farm may thus have more opportunities for reducing the N balances by re-examining fertilizer use, than by decreasing feed imports.

Table 2. Efficiency indicators and the threshold values beyond which farms risk exceeding feasible balances. Orange cells are indicators that exceed the threshold values.

	Indicator to predict likelihood of exceeding feasible balances	Example Farm 2016			High risk of exceeding the feasible balances if		
		N	P	K	N	P	K
1	Balance per acre (lbs/acre)	106	13	29	> 105	> 12	> 37
2	Balance per cwt milk (lbs/hundredweight milk)	1.09	0.14	0.30	> 0.88	> 0.11	> 0.30
3	Milk per cow (lbs/cow/year)		25575		-	< 20000	-
4	Animal density (animal units/acre)		0.8		-	> 1.0	-
5	Whole-farm nutrient use efficiency. (%)	38	45	45	< 44	< 51	< 39
6	Purchased feed (lbs/acre)	107	19	35	> 121	> 20	> 38
7	Feed (tons dry matter/animal unit)		3.7		-	3.5 to 7.5	-
8	Feed use efficiency (milk, %)	28	31	19	< 20	< 25	< 11
9	Homegrown feed (% dry matter)		58		-	< 62-65	-
10	Homegrown forage (%)		40		-	-	-
11	Homegrown grain (%)		23		-	-	-
12	Homegrown nutrients (% dry matter)	41	34	59	< 50	< 50	-
13	Crude protein (CP) and P in all feed (%)	20	0.50	1.51	> 17	> 0.40	-
14	CP and P in purchased feed (%)	28	0.79	1.47	> 30	> 0.60	-
15	CP in homegrown feed (%)	14.5			< 11.8	-	-
16	Fertilizer (lbs/acre)	64	6	18	> 39	> 6	> 38
17	Crop exports (lbs/acre)	11	1	8	< 1	< 1	< 1
18	Manure exports (lbs/acre)				< 1	< 1	< 1
19	Overall crop yield (tons dry matter/acre)		3.3				
20	Acres receiving manure (%)		78				
21	Land in legumes with manure (%)		21				

Although this table of indicators give a general indication of where improvements in nutrient management can be made, it does not provide a detailed and guaranteed protocol to increase production with fewer nutrients. To make improvements in farm management, these results need to be discussed with the farm's nutritionist, crop specialist and planner. Collaboration between these experts can provide a level of detail that is lacking in the NMB. Alternatively, an integrated whole-farm model that links compartments with different farm components can provide a more detailed analysis of nutrient flows and efficiencies on a dairy farm. However, the simplicity of the NMB assessment makes it easy to interpret and relatively quickly to conduct, which is why it is suitable as a key sustainability indicator. This simplicity also makes it an easy exercise to repeat yearly to track a farm's progress, and see the results of management changes over calendar years. Multiple years of NMB assessments also help to filter out the effect of extreme years with bad yields, which may necessitate larger feed imports and would thus result in higher balances.

THE FUTURE OF THE NUTRIENT MASS BALANCE: NEW YORK AND BEYOND

Several other countries have adopted some form of NMB as a tool or a legislative instrument. Dairy farms in The Netherlands are required to assess the nutrient flows on their farm using de Kringloopwijzer, a software model that calculates the movement of nutrients through farm components and estimates specific environmental losses. This approach originates from the mineral accounting system (MINAS), which was introduced at the end of the 1990s (Van den Brandt and Smit, 1998). In New Zealand, the Overseer software is available, which allows for mass balance and nutrient flow calculations for a broader range of farms. Additionally, other countries with a large dairy industry, such as Ireland and Australia use a NMB as indicators as well, although there are differences in approaches and level of detail in the assessments. The exact method may thus vary per location, but the general idea is the same and has proven to be an efficient way to express and monitor sustainable use of nutrients.

In New York, the NMB assessment project has already documented improved whole-farm nutrient balances. Based on NMB assessments from New York farms collected between 2004 and 2013, it was estimated that N and P imports decreased by 20-30% (comparing 2004 and 2013) without a decrease in milk production (Cela et al., 2017). In 2013, imports onto farms were an estimated 66 million lbs of N and 6.6 million lbs of P lower than in 2004. Measures such as precision feeding, improved fertilizer management, and crop management for higher percentage of home-grown forage helped improve the nutrient efficiency and sustainability of farms statewide.

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